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SAFEGUARDS SYSTEMS ANALYSIS RESEARCH AND DEVELOPMENT AND THE PRACTICE OF SAFEGUARDS AT DOE FACILITIES*

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ABSTRACT

Los Alamos Safeguards Systems Group personnel interact with Department of Energy (DOE) nuclear materials processing facilities in a number of ways. Among them are training courses, formal technical assistance such as developing information management or data analysis software, and informal ad hoc assistance especially in reviewing and commenting on existing facility safeguards technology and procedures. These activities are supported by the DOE Office of Safeguards and Security, DOE Operations Offices, and contractor organizations. Because of the relationships with the Operations Office and facility personnel, the Safeguards Systems Group research and development (R&D) staff have developed an understanding of the needs of the entire complex. Improved safeguards are needed in areas such as materials control activities, accountability procedures and techniques, systems analysis and evaluation methods, and material handling procedures. This paper surveys the generic needs for efficient and cost effective enhancements in safeguards technologies and procedures at DOE facilities, identifies areas where existing safeguards R&D products are being applied or could be applied, and sets a direction for future systems analysis R&D to address practical facility safeguards needs.

INTRODUCTION

Safeguards personnel at Department of Energy (DOE) facilities are constantly striving to improve their respective systems in an efficient, cost effective manner. Personnel

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routinely learn to improve existing safeguards performance by attending specialized training courses, workshops, safeguards conferences and new products demonstrations and by inviting others to review their programs. The Safeguards Systems Group at the Los Alamos National Laboratory has been asked to assist several facilities in providing an outside, independent technical review of the current systems and to recommend improvements, if needed, for the facility to consider. These informal reviews allow the Safeguards Systems Group personnel to become familiar with many of the safeguards-related needs throughout the DOE complex and, correspondingly, the solutions that the DOE facilities are employing to alleviate the needs in daily operational safeguards. This working relationship with the facilities has permitted the Los Alamos Safeguards System Group personnel to acquire an in-depth knowledge of safeguards-related needs and their applicable solutions. The relationship also allowed us to provide new and improved techniques to meet the safeguards requirements for protecting, controlling, and accounting for nuclear material. Safeguards research and technology development cannot be effectively accomplished without a working relationship and positive interaction with the facilities requesting assistance.

Several of the needs that are common to DOE facilities are derived from requirements in the safeguards-related orders, especially DOE Order 5633.3. These needs do not necessarily represent any failure to adequately protect nuclear materials but represent areas where protection could be improved or made more efficient. The following, then, are some important technical areas that are candidates for improvement in many DOE facilities.

Measurement Control – the procedures and activities used to ensure that a measurement process generates measurements of sufficient quality for their intended use and provides measurement uncertainty statements used in calculating control limits;

Accounting for Nuclear Material – the practices of systematically recording, reporting, and interpreting nuclear material transactions and inventory data and information, *System Performance Evaluation* – a safeguards program tool used to determine how effectively the system's detection elements meet the nuclear material protection requirements;

Material Control in Process Areas – the part of safeguards that detects or deters theft or diversion during the processing of nuclear materials;

Safeguards Integration – coordination of safeguards activities and systems with those for physical protection, process control and monitoring, and ES&H to deter, detect, and respond to unauthorized possession, use, or sabotage of special nuclear material; and

System Design – application of safeguards, computerized system design, and information management principles in the construction of a new facility or in the upgrade of an existing facility to meet the requirements for the control and accounting of nuclear materials.

The remainder of this paper will discuss these areas and present typical and special resolutions to assure that the safeguards implemented by the facilities meet the DOE Orders for the control and accounting of nuclear materials efficiently and cost effectively.

DISCUSSION

Measurement Control

The importance of accountability measurement results cannot be underestimated because these assay values are used to determine input/output, inventory, and shipper/receiver accounting values. Without an adequate measurement control program, the quality of the measurements and the validity of decisions based on the measurements cannot be assured. Unfortunately, there is no hard-and-fast rule or solve-all-problems software program capable of meeting every facility's needs. But there are good general practices that will be applicable for nearly every circumstance. These suggestions are presented below.

The nuclear material analysis support, whether it be destructive or nondestructive techniques, is generally provided by a staff of chemists, physicists, analysts, and support personnel. Such a staff can routinely perform up to

100 000 individual method determinations per year using a variety of analytical techniques, a portion of which are used for nuclear material accountability purposes. The bulk of the methods are designed for service at multiple measurement points structured to support the process operations over a range of material forms and concentrations.

Measurement control for safeguards purposes often involves interaction with measurements personnel who are operationally independent of the safeguards organization. The primary responsibility of the safeguards organization is to assure control of the measurement processes used for accountability purposes. This control can be demonstrated through the use of statistical tests on the measurement control data. Therefore, the safeguards personnel must have access to control data that have been generated under analysis conditions identical to those employed for accountability analyses. The measurement control samples/standards must have a composition as near as possible to the accountability sample over the expected measurement ranges. Sufficient numbers of control samples/standards must be processed to provide a valid statistical sampling to obtain a statistical model of the method.

The control data should be subject to a normal distribution test, trends analysis, mean square successive differences, and a runs test. Covariance tests can also be performed to check relationships such as analyst and method performance based upon time of day, sample type, measurement control sample, etc. Upon completing these tests, a model is developed and bias and precision parameters are determined. The main purpose of these tests is to assure that all measurement control data are acceptable for use in providing statistical information concerning nuclear materials accountability assay results. The parameters can then be used to bias correct results and assign precision estimates covering the active method range. When these controls are analyzed before or in conjunction with the accountability samples, they ensure that a measurement method and an analyst will demonstrate acceptable performance before the assay results are used for nuclear materials accounting. If the control result fails statistical tests, the accompanying accountability result is suspect.

Adhering to guidance recommending a rigorous measurement control program similar to that suggested above provides nuclear material accountability assay results that have a documented pedigree and are nearly beyond question. A variety of statistical tools are now available including the software MCCAT[1] (Measurement Control Charts and Tests), which organizes and statistically analyzes measurement control data and graphically displays the data on a computer monitor. In addition, to facilitate the exchange of state-of-the-art techniques, new ideas, and the methods that can be employed to fulfill the DOE nuclear materials measurement control requirements, the Los Alamos Safeguards Systems Group continues to participate in workshops and conduct DOE-sponsored training courses.

Accounting for Nuclear Material

Some nuclear materials accounting is based on old labor intensive "ledger entry" methods rather than on modern, computerized accounting techniques. In many instances, transfer and inventory information is hand entered into a spreadsheet-type computer system to help track and account for the materials. However, such systems are often slow and man-power intensive with regard to data entry and interpretation. This conventional accounting involves careful measurement and reporting of all transfers through specified measurement points only at the boundary of the accounting area. This accounting technique requires shutting down the process to flush out nuclear material to complete the inventory. Timely detection of theft and diversion can be improved and made more efficient by using modern methods. Nuclear materials accounting programs are becoming available that, in some cases, can be integrated into or can replace existing systems. These new programs can be much more effective in meeting the new performance-based requirements.

In response to the desire to make the accounting systems more timely and, hence, more useful as a real-time detection element, near-real-time accounting (NRTA) and running-book-inventory (RBI) systems have been developed and implemented by some facilities. NRTA uses the conventional accounting measurements of materials crossing the material balance area boundaries. This technique also employs measurements that are important to inventories in conventional accounting, but these measurements are made at frequent intervals without interrupting the process. These in-process inventories use estimates of holdup in processing equipment and are based on a few key operating parameters. RBI assumes an in-process inventory calculated from available processing information. This approach uses the cumulative quantities of nuclear materials that cross the accounting area boundaries normally obtained using conventional practices and also statistically evaluates the variations in this inventory. Such analyses are being developed for use with the NucMAS materials accounting system at the Savannah River New Special Recovery.[2]

Advanced NRTA and RBI applications have been teamed with process monitoring to track and account for nuclear material as it moves through the operational processes. Solution processes are tracked by monitoring valve positions, pump and jet operation, dilution effects, tank volumes, solution densities, and concentrations. Anomaly detection routines, such as WISDOM and SENSE,[3] can be applied to this information to detect unusual activity in near-real-time. For process systems that handle solid materials, nuclear materials tracking may include balances/scales, glovebox entry monitors, glovebox atmospheric and pressure sensors, and nuclear material sensors outside the glovebox. In all cases, the process monitoring systems for safeguards purposes are designed to automatically account for the nuclear material as it moves through the processing steps.

NRTA principles have been employed to produce dynamic materials accounting techniques in which personnel enter the nuclear material movement, physical data, and control information into a safeguards computer system, and obtain a go or no-go result before receiving approval for material movement. Such systems demonstrate separation of duties, materials tracking and accounting, and provide for an increased timeliness factor in use as a system's detection element. Los Alamos Safeguards Systems Group personnel at the Argonne National Laboratory–West's Fuel Manufacturing Facility are helping to demonstrate this concept using the PC-DYMAC nuclear materials accounting system.[4]

System Performance Evaluation

The need to complete a self-examination of a safeguards system results from the performance requirements called out in the DOE Orders. Generally, the design of a performance testing program is focused on after-the-system-installation testing of critical detection elements, which may be considered the primary line of defense. Most of these primary detection elements are designed to detect nuclear material theft or diversion. Some detection elements may be used primarily for assurance that theft has not occurred—something many security detection elements cannot provide. Various software tools have been developed to aid in system design and analysis, either for upgrades or for new facility's systems. These programs, e.g., BATLE,[5] SAVI,[6] ET,[7] are used primarily to assess the performance of the physical security system or materials control systems. Software systems that can incorporate outsider and insider threats are currently being developed and tested. Programs, such as FACSIM[8] that can simulate the dynamics of facility operation as well as personnel and nuclear material movement, are being structured to identify weaknesses in existing systems and to point out needed improvements in new facility design plans. Other software, such as the THIEF program,[9] models the facility's detection elements in the program and allows the user to play the role of the insider trying to remove nuclear material from the facility. The VP (variance propagation) program[10] may be used as an MC&A measurements systems analysis tool to analyze optimum accountability performance. MAWST (Materials Accounting with Sequential Testing)[11] is used to evaluate variance propagation. The overall philosophy of these software programs is to provide facility safeguards personnel with a variety of tools to help evaluate the ways that their detection elements could be exploited by insiders and assist in identifying and evaluating designs and upgrades.

Upon installation, individual detection elements should be tested to prove adequate performance as part of a defense-in-depth structure. These tests will involve simulations of probable situations, as well as some limited-scope testing, but will be somewhat perturbed by the fact that the test scenario does not carry the exacting conditions that would be seen in a real situation.

Diversion Path Analysis (DPA)[12] does not routinely rely upon computer software to perform a safeguards system assessment. A team of safeguards experts studies the nuclear material processes, including packaging, shipping, receiving, storing, and other process handling procedures, and completes a structured analysis of all possible theft and diversion paths that might be used. This process identifies weaknesses in the nuclear material safeguards and security system that can be evaluated for risks, costs, and benefits. Currently, Los Alamos Safeguards Systems personnel are leading a team to provide DPA assessments at several facilities.

Material Control in Process Areas

Nuclear materials control in operating process areas provides the greatest challenge for safeguards personnel. Nuclear materials control involves controlling access to the material, controlling the movement of the material, and controlling the measurement of the material. In some instances, necessary control of material may be deemed impossible due to processing constraints, such as hands-on handling of solid nuclear materials for machining, packaging, or recycling procedures. Aqueous or gaseous systems are just the opposite of solid processing systems because the material is contained in vessels and pipework that could be subject to an in-depth process monitoring program. Regardless of the system, detecting an abnormal condition concerning nuclear materials control in process areas is a challenge.

An effort currently under development concerns data gathered during processing that could be used to develop a normal operating conditions database that all new, incoming data could be compared against. Such a system could rapidly detect upset, off-normal, or abnormal conditions that would indicate possible diversion or theft of nuclear material. This system could be designed as an expert system with all rules and conditions coded within the software. However, a more efficient program would allow an artificial intelligence-based program to develop its own rules against which all incoming data could be compared. Such a system, in the advanced development stage in the Safeguards Systems Group at Los Alamos, is the WISDOM and SENSE[3] anomaly detection rule-based program. It would be responsive to changing operating conditions. Another LANL software design involves the use of neural networks[13] that are interrelated algorithms linked to nuclear material processes. Data or information brought into the software produces appropriate responses that can be employed to identify anomalous conditions, which may indicate material is not being controlled. This artificial intelligence software can provide decisions for appropriate response without human interaction or can provide alternate decisions for human consideration.

Nuclear materials control requires controlling of access to the material. This can be accomplished by controlling the people or by controlling the material. Personnel control using access control booths (PACBs) requires identity verification to enter and are designed to prevent piggybacking. Some safeguards systems that can also be claimed as physical protection systems involve monitoring the material in storage locations. This involves automated, computer-controlled image processing[14] of material storage containers to determine if a container has been moved. Similarly, infrared imaging[15] can be used to determine if the contents of a container have changed or if the container has been moved. For large storage areas, a laser grid[16] could cover the storage area and detect access whenever a laser beam is severed. Other systems involve placing a motion sensor[17] on the nuclear material container to detect movement or a fiber-optics-based bar code system[16] that would constantly scan a code on a storage container to provide assurance that the container was present. A two-man rule could be employed for hands-on systems; closed-circuit television could monitor appropriate process conditions; and a knowledgeable security inspector could be present to monitor any material handling. However, a more efficient and cost effective system would involve technology without requiring human interaction to detect anomalous conditions. Whatever the particular element chosen, it should not be depended upon solely to detect anomalous conditions but should be part of a defense-in-depth system such that a single failure would not compromise system assurance.

Safeguards Integration

The DOE definition of safeguards is "an integrated system of physical protection, material accounting, and material control measures designed to deter, prevent, detect, and respond ... ." Integration, from a safeguards standpoint, can be taken as the efficient processing and use of diverse information to detect theft and diversion. The elements of an integrated safeguards system would be linked together to provide a broad-based defense-in-depth. Although many facilities in the DOE complex have the detection elements that are necessary to form an integrated system, the individual elements are not linked and, therefore, are functioning independently. Typically, such systems are not very efficient—relying on humans to compile and process the diverse information and eventually reach a safeguards decision. Such systems require multiple alarm and response assessment capabilities, generally independent of each other.

Some technology development is directed towards individual detection elements that provide information used to detect anomalous conditions. With the vast quantity of data and information being collected from various detection elements, human detection and response may miss an anomalous condition. In other cases, multiple alarm conditions from different data sources might be needed to arrive at a conclusion concerning an incident. Such conditions would require timely human sorting and compiling of data to reach the correct solution. Correlation of safeguards and security information is highly desirable because of the benefit of increased usage of available data and the added efficiency of automated analysis.

An integrated safeguards system is an advanced information and distributed control system to collect information and data and prevent its loss. These systems provide the means to monitor the safeguards and security detection elements throughout the facility. However, correlation and interpretation of large quantities of safeguards and security information cannot be achieved efficiently nor in a timely fashion when performed by hand. R&D programs currently under development by the Los Alamos Safeguards Systems Group would correlate the information to reach logical conclusions in a time frame to allow a timely response to anomalous conditions. As discussed above, the WISDOM and SENSE program[3] will generate its own rules concerning process and alarm conditions to identify atypical information. Other software being designed using neural network configurations[13] will permit anomaly and alarm information to be correlated and interpreted for materials control and accountability and physical protection systems. This software and others currently under consideration for development will be decision-support-based. These programs will allow a human to make an informed and timely decision concerning the response to a single event or series of events, or will permit the system to automatically select and initiate an appropriate response.

Systems Design

A major factor influencing implementation of safeguards detection elements at all DOE facilities is cost. Other than budget, the consideration for new safeguards elements for an existing system is to assure that the new equipment will be compatible with or enhance existing safeguards elements. Several of the recently developed programs discussed above can be beneficial in selecting new components as well as estimating the effect the component will have on the overall system performance. In particular, FACSIM[8] can be used to identify the system's weaknesses and examine the effect the new element will have on the newly configured system. The augmented variance propagation program,[10] VP, can be used to evaluate proposed improvements to the accountability sampling and measurement program.

Safeguards systems being designed for new facilities can benefit by using all of these programs. FACSIM can be used to evaluate the proposed system; THIEF[9] can be employed to simulate the actions of an insider on the proposed system. A newly developed program, Resource Allocation for the Optimization of Safeguards (RAOPS),[18] can aid in the selection of the best set of safeguards elements for a fixed amount of resources. It is based upon the configuration of safeguards elements that maximizes the minimum detection probability against a range of scenarios for theft or diversion under the constraint of fixed safeguards resources. LAVA[19] (Los Alamos Vulnerability/Risk Assessment) software assesses vulnerabilities in computer, information and operations security systems, and nuclear safeguards systems. These programs are tools to help an analyst design a new safeguards system as well as select upgrades for existing facilities.

These programs can help us to evaluate the effect that new systems may have on safeguards at a facility; but, unfortunately, they cannot tell us which detection elements the facility should employ for each situation. Knowledge, experience, specialized training, and process experience all play a key role in designing a system to meet the DOE requirements for the safeguarding of nuclear material. The key element in system design is still the expert who can review systems, spot problems, and employ available tools. The Los Alamos Safeguards Systems Group is playing several key roles in system designs at facilities in the planning stages and at facilities upgrading and improving existing systems.

CONCLUSION

The materials control and accountability system should perform its required functions while being as transparent as possible to the operations personnel. Many other facility benefits are spin-offs from the R&D efforts to improve safeguards systems. For example, a well designed safeguards system with which nuclear material can be maintained with high surety might indicate that a daily administrative check or a routine inventory is not necessary; this would result in decreased radiation dose to safeguards personnel. A personnel tracking system used to control personnel access to nuclear material would also be able to locate individuals during emergency conditions. Controlling movement of nuclear material would also enable criticality safety. Efficient safeguards systems, because of detailed knowledge of the location and amounts of materials, provide many benefits to process, safety, criticality, and environment programs.

Current research and technology development efforts involving safeguards systems are directed towards demonstrating acceptable performance of the safeguards detection elements. Without actually testing the detection system with real nuclear material, the goal of the simulation or modeling program is to evaluate the facility's integrated safeguards and physical protection system to show that it has been designed and implemented correctly and that it will meet the DOE performance requirements. More specific R&D directions include evaluating existing technologies employed in other arenas for possible application into the materials control and accountability spectrum of needs.

The safeguards technology development community is responding to the wide range of needs of the facilities in the DOE Complex. In particular, our working relationship with facility personnel, DOE Operations Offices, and the Office of Safeguards and Security allows an atmosphere that facilitates problem-solving. Technical assistance may begin with a review of current safeguards systems to determine the depth of efforts that may be required to help rectify outstanding needs and is usually completed when a list of suggested options has been discussed with the facility. In some instances, work continues until systems have been demonstrated to perform adequately, either through simulation and modeling or actual performance testing. Similarly, R&D efforts are geared to develop new materials control and accountability techniques and to facilitate the applications of materials control and accountability requirements.

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